



1803/6484  
#2  
INVESTOR IN PEOPLE

**PRIORITY  
DOCUMENT**  
SUBMITTED OR TRANSMITTED IN  
COMPLIANCE WITH RULE 17.1(a) OR (b)

MAILED 04 MAY 2004	
WIPO	PCT

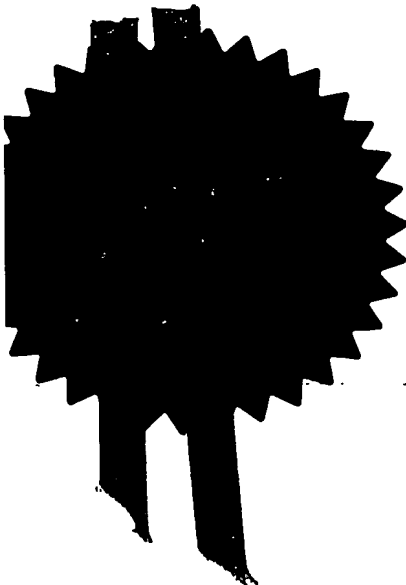
The Patent Office  
Concept House  
Cardiff Road  
Newport  
South Wales  
NP10 8QQ


I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.



Signed   
Dated 21 April 2004

Patents Form 1/77

THE PATENT OFFICE

Patents Act 1977  
(Rule 16)

27 NOV 2002

RECEIVED BY FAX

28NOV02 E766802-1 C21729  
P01/7700 0.00-0227687.1**Request for grant of a patent**

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road  
Newport  
South Wales  
NP10 8QQ

1. Your reference

PotBar

2. Patent application number

(The Patent Office will fill in this part)

27 NOV 2001

0227687.1

3. Full name, address and postcode of the or of each applicant (underline all surnames)

Borealis Technical Limited,  
Suite 3G, Eurolife Building,  
1 Corral Road,  
Gibraltar

08516411001

Patents ADP number (If you know it)

If the applicant is a corporate body, give the country/state of its incorporation

Gibraltar

4. Title of the invention

Method for increasing efficiency of thermotunnel devices

5. Name of your agent (If you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

44 Swing Gate Lane  
BERKHAMSTED  
Hertfordshire  
HP4 2LL

Patents ADP number (If you know it)

0418467001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country

Priority application number  
(if you know it)

Date of filing  
(day / month / year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
(day / month / year)

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if...

No

a) any applicant named in part 3 is not an inventor, or  
b) there is an inventor who is not named as an applicant, or

c) any named applicant is a corporate body.

See note (d))

**Patents Form 1/77**

1. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form

Description

Claim(s) 2

Abstract 1

Drawing(s) 3

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

Request for substantive examination (Patents Form 10/77)

Any other documents (please specify)

11.

I/We request the grant of a patent on the basis of this application.

Signature

S Harbron

Date

27 November 2002

12. Name and daytime telephone number of person to contact in the United Kingdom

Dr Stuart Harbron - 01442 384084

**Warning**

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

**Notes**

- If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.
- Write your answers in capital letters using black ink or you may type them.
- If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.
- If you have answered 'Yes' Patents Form 7/77 will need to be filed.
- Once you have filled in the form you must remember to sign and date it.
- For details of the fee and ways to pay please contact the Patent Office.

0053914 27-Nov-02 10:17

-1-

## Method for increasing efficiency of thermotunnel devices

### Field of Invention

This invention relates to thermotunneling and thermionic devices

### 5 Background of the Invention

Simple thermotunnel device comprising two metallic electrodes separated by vacuum gap has energy diagram shown in Figure 1 (image charge modification of the barrier shape is omitted for simplicity). 10 and 12 are metallic electrodes separated by a distance  $d_0$  in a vacuum (U.S. Patent No. 6,417,060; WO99/13562). The cooling power and efficiency of such devices have been calculated by Hishinuma et al. [Appl. Phys. Letters (2001) 78(17):2572-2574], who show that that electrons having a wide spectrum of energies take part in heat pumping. Thus, both electrons 14 sitting at low energy levels (around the Fermi level,  $F_0$ ) and electrons sitting at higher energy levels 16 take part in tunneling through the potential barrier and transfer heat from electrode 10 to electrode 12 (see Figure 1; for simplicity it is assumed that work functions,  $\Phi$ , of two electrodes are equal and equal to applied voltage  $eV_{bias}$ ). Tunneling of low energy electrons leads to low efficiency heat pumping. Pumping of low energy electron requires the same work from external source as pumping of high energy electron ( $eV_{bias}$  in both cases). At the same time low energy electrons remove less heat from the emitter than high energy electron. Besides that in some cases tunneling of low energy electron might cause negative heat flow.

### Disclosure of Invention

25 From the foregoing, it may be appreciated that a need has arisen for a means for shifting to higher energies the spectrum of energies of electrons that are involved in tunneling.

The present invention comprises a tunneling device in which the collector electrode is modified so that tunneling of higher energy electrons from the emitter electrode to the collector electrode is enhanced.

30 In one embodiment, the collector electrode is in contact with an insulator layer disposed between the collector and emitter electrodes.

-2-

The present invention additionally comprises a method for enhancing tunneling of higher energy electrons from an emitter electrode to a collector electrode, the method comprising the step of contacting the collector electrode with an insulator, and placing the insulator between  
5 the collector electrode and the emitter electrode.

The present invention additionally comprises a method for cooling comprising applying a bias voltage to an emitter electrode; placing a collector electrode a distance  $d_0$  from the emitter electrode; placing an insulator layer a distance  $d_1$  from the emitter electrode; and contacting  
10 the insulator layer and the collector layer, whereby electrons tunneling from the emitter electrode to the collector electrode and the emitter electrode, thereby cooling the emitter electrode.

#### Brief Description of Drawings

For a more complete explanation of the present invention and the technical  
15 advantages thereof, reference is now made to the following description and the accompanying drawing in which:

Figure 1 is a diagrammatic representation of energy levels in prior art tunneling devices.

Figure 2 is a diagrammatic representation of prior art tunneling devices  
20 (Figure 2a) and a tunneling device of the present invention (Figure 2b).

Figure 3 is a diagrammatic representation of potential energy-distance profiles for prior art tunneling devices (Figure 3a) and a tunneling device of the present invention (Figure 3b).

#### Best Mode for Carrying Out the Invention

25 Embodiments of the present invention and their technical advantages may be better understood by referring to Figures 2 and 3.

It is well known that when an electric field  $E$  is applied to an insulator it causes polarization of the insulator atoms and the resulting field is decreased inside the insulator. Thus the field inside the insulator,  $E_1$  is  
30 equal to  $E/\epsilon$ , where  $\epsilon$  is the dielectric constant of the insulator.

Referring now to Figure 2a, which shows a prior art tunneling device, an emitter electrode 22 and a collector electrode 24 are separated by a vacuum gap. Upon application of an external voltage 20,  $V_{bias}$ , the field in the vacuum area between the electrodes is  $E$ .

-3- .

Referring now to Figure 3a, which shows the relationship between potential energy  $E$  and electrode separation  $x$  for the two electrodes of Figure 2a, high energy electrons 32 and low energy electrons 34 are able to tunnel across the energy barrier. The high energy electrons have to overcome a thinner barrier than the low energy electrons, but the lower energy levels around the Fermi level are much more highly populated than the higher energy levels, and thus the efficiency of heat pumping is low, as discussed above.

Referring now to Figure 2b, which shows a tunneling device of the present invention, in addition to electrodes 22 and 24, an insulator 28 is placed between the electrodes and attached to the collector electrode. This creates a field  $E_1$  inside the insulator layer and field  $E_2$  in the vacuum between the insulator and metallic electrode. The field inside the insulator will therefore decrease and the field in vacuum gap between the insulator and metallic electrode will increase, and thus  $E_2 > E > E_1$ .

Referring now to Figure 3b, which shows the relationship between potential energy  $E$  and electrode separation  $x$  for the two electrodes of Figure 2b, high energy electrons 32 and low energy electrons 34 are able to tunnel across the energy barrier as in Figure 3a. Now, however, when the same  $V_{bias}$  is applied, the relationship between energy and distance has two slopes: in the range  $0 - d_1$ , the slope corresponds to field  $E_2$  in the vacuum between the insulator and emitter electrode, and in the range  $d_1 - d_0$  the slope corresponds to the field  $E_1$  inside the insulator. It is obvious that now the high energy electrons of Figure 3b have to overcome a thinner barrier than electrons with the same energy in Figure 3a, while at the same time tunneling conditions for low energy electrons remain approximately the same (compare Figures 3a and 3b). In this way, for the electrode arrangement of Figure 2b, the energy spectrum of the tunneling electrons will shift in the direction of higher energies, which will in turn dramatically increase COP (Coefficient of Performance or useful cooling power).

One more advantage of the invention is that adding insulator layer prevents electrodes from shorting. Electrodes having large areas of surfaces tend to touch each other in some places which cause local electric shock and damage the surfaces of the electrodes. Adding insulator layer prevents electrodes from it. Because of that offered device has lower requirements on electrode surface flatness and is easier to make.

The following is given by way of example to illustrate the present invention, as is not intended to limit the scope of the present invention. Referring again to Figure 2b, which shows a tunneling device of the present

-4-

invention, an emitter electrode 22 and a collector 24 are separated by a distance  $d_0$  of 150Å, and an insulator layer 28 of thickness  $d_0 - d_1$  of 120Å, and the gap between insulator layer 28 and emitter 22  $d_1$  is 30Å. In a preferred embodiment, the insulator layer is a metal oxide. In a particularly preferred embodiment the insulator layer is aluminum oxide. Field  $E$  created by bias voltage 20,  $V_{bias}$ , is applied across the device. For aluminum oxide, the dielectric constant is about 10, which means that in the first approximation field  $E_2$  could be neglected. Consequently the entire field will be concentrated inside thin 30Å vacuum layer between insulator and metal electrode. The applied voltage,  $V_{bias}$ , may be therefore be reduced to a approximately a fifth of the value utilized in the absence of the insulator layer to achieve the same field strength.

Furthermore, Hishinuma et al. calculate useful cooling coefficient or COP values for a range of inter-electrode spacing and electrode work functions, and show that COP is inversely proportional to the applied voltage ( $V_{bias}$ ). Thus for the example above the bias voltage could be over four times lower to get the same cooling power. Because COP is inversely proportional to  $V_{bias}$  it will result in approximately 5 times increase of COP. In reality COP will increase more than that because of filtering effect of potential barrier.

While this invention has been described with reference to specific embodiments, it is to be understood that this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments will be apparent to persons skilled in the art upon reference to this description. It is to be further understood, therefore, that numerous changes in the details of the embodiments of the present invention and additional embodiments of the present invention will be apparent to, and may be made by, persons of ordinary skill in the art having reference to this description.

For example, particular values for the separation of the electrodes, the thickness of the insulator, and the distance between the insulator and the emitter are given in the foregoing. Other values may be used without departing from the scope of the present invention. Thus the distance between the electrodes may be in the range of 10 - 200Å, and the distance between the emitter and the insulator layer may be in the range of 5 - 50Å.

Specific methods for the fabrication of devices of the present invention have not been given as there are a number of approaches that may be used by one of ordinary skill in the art to achieve the objectives of the present invention. Thus the devices may be fabricated by attaching a pre-formed

-5-

insulator layer to the collector electrode, or the insulator layer may be deposited onto the collector electrode. For example, a layer of aluminum oxide may be deposited onto the surface of the collector by reactive DC magnetron sputtering of aluminum in the presence of oxygen.

- 5 Thermotunneling devices of the present invention may be used for cooling applications, in which case the emitter electrode is in thermal contact with a heat source, and the collector electrode is in contact with a heat sink.

10



-6-

Claims

1. A thermotunneling device comprising a collector electrode, an emitter electrode and an insulator layer, wherein the insulator layer is disposed between the emitter electrode and the collector electrode,  
5 and is touching the collector electrode.
2. The thermotunneling device of claim 1 in which the insulator layer comprises a metal oxide.
3. The thermotunneling device of claim 2 in which the metal oxide is aluminum oxide.
- 10 4. The thermotunneling device of claim 1 in which the distance between the electrodes is in the range of 10 - 200Å.
5. The thermotunneling device of claim 1 in which the distance between the emitter and the insulator layer is in the range of 5 - 50Å.
- 15 6. The thermotunneling device of claim 1 in which the emitter electrode comprises a metal.
7. The thermotunneling device of claim 1 in which the collector electrode comprises a metal.
- 20 8. A method for enhancing electron tunneling between an emitter and collector electrode comprising the step of contacting the collector electrode with an insulator, and placing the insulator between the collector electrode and the emitter electrode.
9. The method of claim 8 in which the insulator layer comprises a metal oxide.
- 25 10. The method of claim 9 in which the metal oxide is aluminum oxide.
11. The method of claim 8 in which said placing step comprises placing the insulator between 5 and 50Å from the emitter electrode

-7-

12. The method of claim 8 additionally comprising the step of placing the collector electrode between 10 and 200Å from the emitter electrode.
13. The method of claim 8 in which the emitter electrode comprises a metal.
14. The method of claim 8 in which the collector electrode comprises a metal.
15. A method for cooling comprising the steps:
- (a) applying a bias voltage to an emitter electrode;
  - (b) placing a collector electrode a distance  $d_0$  from the emitter electrode;
  - (c) placing an insulator layer a distance  $d_1$  from the emitter electrode; and
  - (d) contacting the insulator layer and the collector layer,
- whereby electrons tunneling from the emitter electrode to the collector electrode and the emitter electrode thereby cooling the emitter electrode.
16. The method of claim 15 in which  $d_0$  is in the range of 10 - 200Å.
17. The method of claim 15 in which  $d_1$  is in the range of 5 - 50Å.

-8-

ABSTRACT

The present invention comprises a tunneling device in which the collector electrode is modified so that tunneling of higher energy electrons from the emitter electrode to the collector electrode is enhanced.

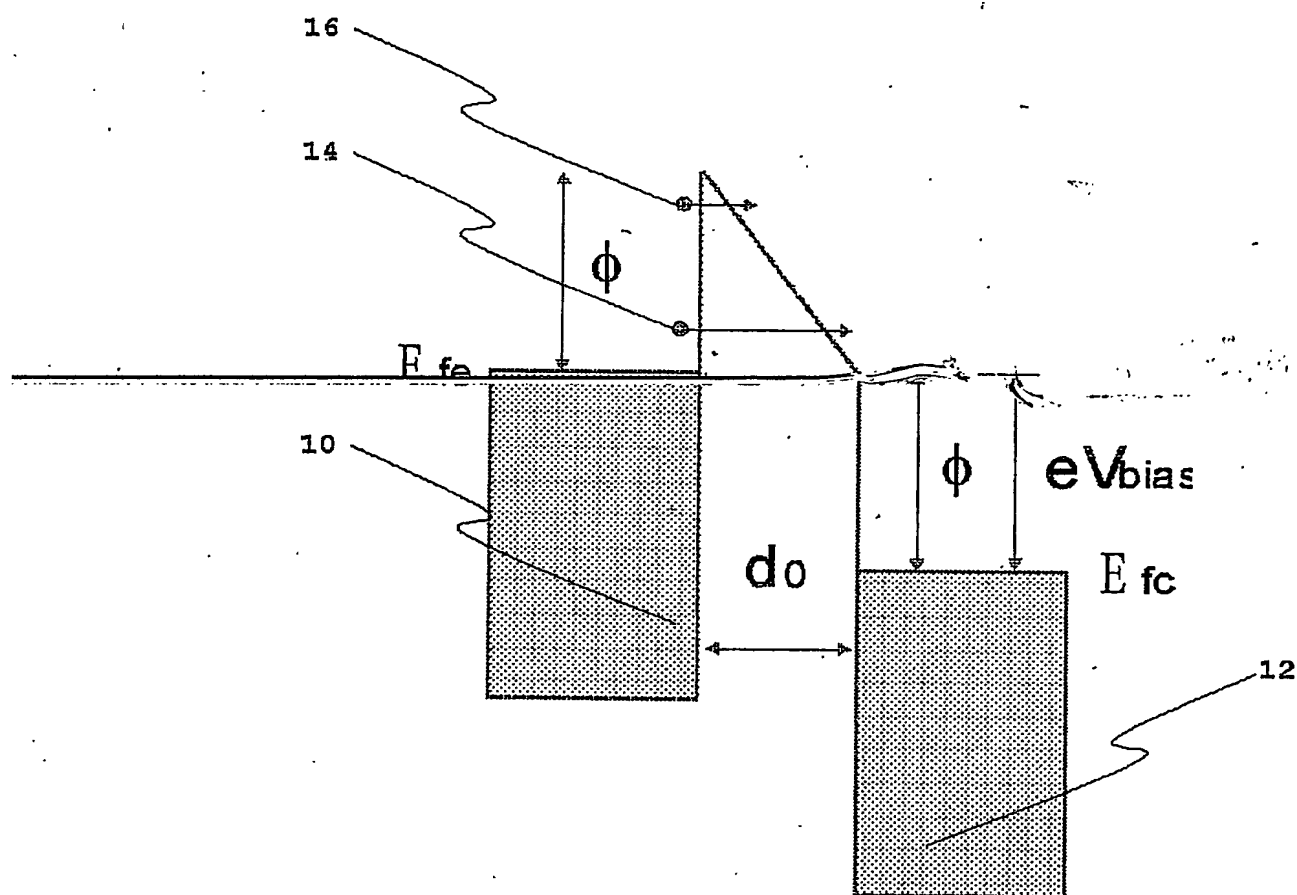
- 5 In one embodiment, the collector electrode is contacted with an insulator layer, preferably aluminum oxide, disposed between the collector and emitter electrodes.

- 10 The present invention additionally comprises a method for enhancing tunneling of higher energy electrons from an emitter electrode to a collector electrode, the method comprising the step of contacting the collector electrode with an insulator, preferably aluminum oxide, and placing the insulator between the collector electrode and the emitter electrode.

15

1/3

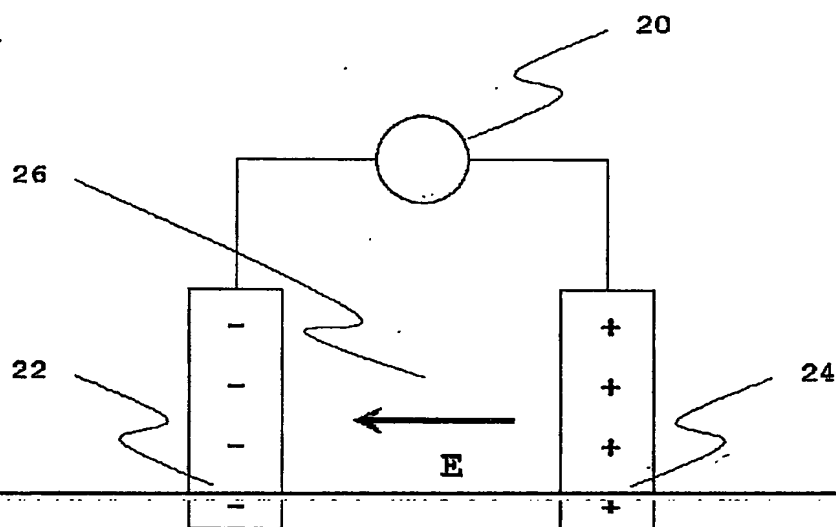
Figure 1



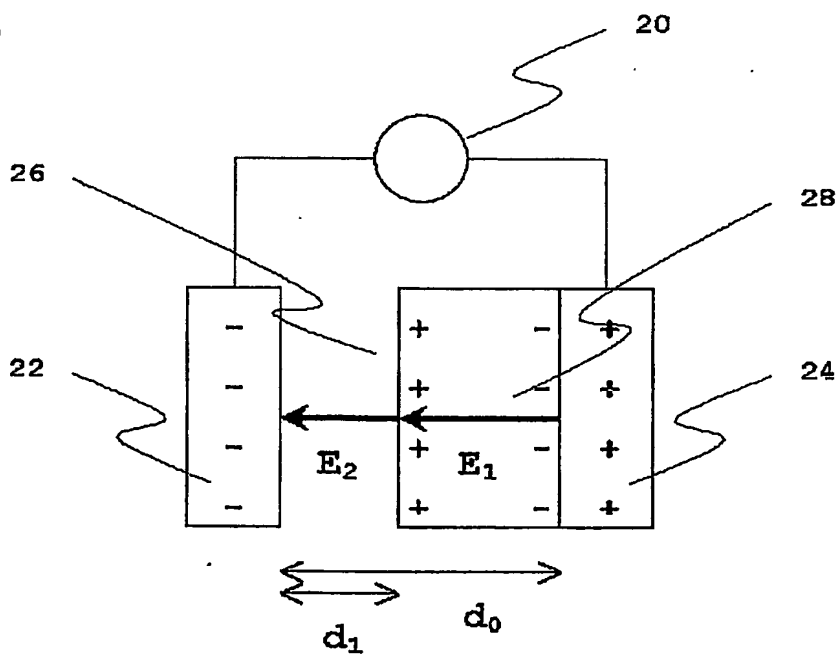
2/3

Figure 2

2a



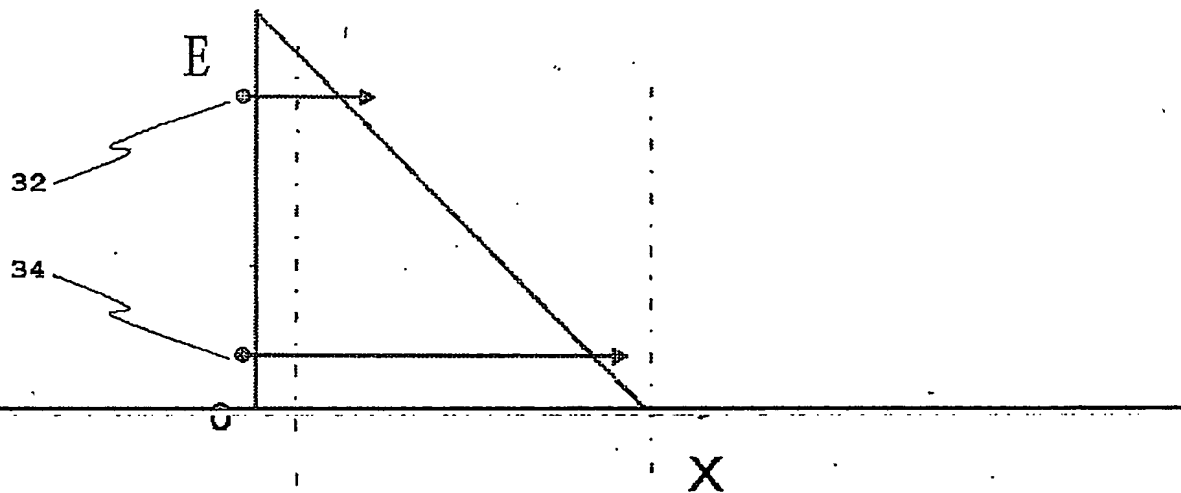
2b



3/3

Figure 3

3a



3b

